BOSTON COLLEGE

INSTITUTE FOR SCIENTIFIC RESEARCH

TO: Defense Technical Information Center
8725 John J. Kingman Road, Suite 0944
Fort Belvoir, VA 22060-6218

FROM: Daneille Berzinis
Assistant Director, Institute for Scientific Research

Enclosed please find one (1) copy of the Final Report for Naval Research Laboratory Grant No. N00173-10-1-G001.

140 COMMONWEALTH AVENUE, CHESTNUT HILL, MASSACHUSETTS 02467
617-552-8773 FAX 617-552-2818

FINAL REPORT

NRL Grant No. N00173-10-1-G001

CME Research and Space Weather Support for the SECCHI Experiments on the STEREO Mission

by

David F. Webb, Principal Investigator
Institute for Scientific Research
Boston College
140 Commonwealth Avenue
Chestnut Hill, MA 02467-3862
Email: david.webb@bc.edu

submitted to

Dr. Russ Howard
Naval Research Laboratory
4555 Overlook Ave., SW
Washington, DC 20375-5320

on

14 January 2014

INSTITUTE FOR SCIENTIFIC RESEARCH

BOSTON COLLEGE, CHESTNUT HILL, MA 02467

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
14-01-2014	FINAL	15-10-2009 – 14-10-2013

4. TITLE AND SUBTITLE
CME RESEARCH AND SPACE WEATHER SUPPORT FOR THE SECCHI EXPERIMENTS ON THE STEREO MISSION

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00173-10-1-G001

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
David F. Webb

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Boston College
140 Commonwealth Avenue
Chestnut Hill, MA 02467

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
4555 Overlook Ave SW
Washington, DC 20375

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT The work was a 3-year Phase E effort focused on coronal mass ejection (CME) and space weather research as applied to the STEREO mission program. This work included 1) Developing programs and techniques for the reduction and analyses of the data returned from the STEREO SECCHI instruments regarding the origin of CMEs, their transport through the heliosphere, and interaction with Earth's environment. The SECCHI data being returned provide stereo views of the Sun, the corona and CMEs, and yield fundamentally new insights into the 3-dimensional structure of the Sun's corona and CMEs. Our work involved the development of new and innovative approaches to performing the data analysis, including comparisons with other STEREO instruments, and other data sets where appropriate; 2) Analysis of the stereo imaging data from the SECCHI Heliospheric Imager (HI) instrument. The analysis techniques for the HI data required comparisons with other STEREO instruments, data from the Solar Mass Ejection Imager (SMEI); 3) Coordinating and developing space weather-related research and forecasting tools for SECCHI and STEREO, including near-real time monitoring and analyses of the imaging data returned from the SECCHI experiments, primarily using Beacon data.

15. SUBJECT TERMS
Coronal Mass Ejections (CME), space weather, STEREO mission, SECCHI instrumentation, heliospheric imaging, Solar Mass Ejection Imager (SMEI) mission, near real-time forecasting

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			David Webb
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	SAR	16	617-552-6135

TABLE OF CONTENTS

1. INTRODUCTION

This work was a three-year Phase E effort focused on coronal mass ejection (CME) and space weather research as applied to the STEREO mission program. This work included:

- Developing programs and techniques for the reduction and analyses of the data returned from the STEREO SECCHI instruments regarding the origin of CMEs, their transport through the heliosphere, and interaction with Earth's environment. The SECCHI data being returned provide stereo views of the Sun, the corona and CMEs, and yield fundamentally new insights into the 3-dimensional structure of the Sun's corona and CMEs. Our work involved the development of new and innovative approaches to performing the data analysis, including comparisons with other STEREO instruments, and other data sets where appropriate;
- Analysis of the stereo imaging data from the SECCHI Heliospheric Imager (HI) instrument. The analysis techniques for the HI data required comparisons with other STEREO instruments, data from the Solar Mass Ejection Imager (SMEI), and other appropriate data sets. The combination of the limited-field HI and all-sky SMEI observations form a unique data set requiring innovative approaches to its analysis. This work has led to fundamentally new insights into CMEs;
- Coordinating and developing space weather-related research and forecasting tools for SECCHI and STEREO, including near-realtime monitoring and analyses of the imaging data returned from the SECCHI experiments, primarily using Beacon data.

The grant for this work was awarded following our proposal submitted in March 2009 in response to the NRL Broad Agency Announcement No. 76-07-01 "Research Into Space – Its Imaging and Modeling". This work was performed over the original three-year period and was extended at no additional cost to 14 October 2013. This grant was the successor to the previous NRL grant no. N00173-07-1-G016, titled "Analysis of Data on CMEs and Space Weather Support for the SECCHI Experiments on the STEREO Mission", with a period of performance from 30 May 2007 - 31 December 2009 (Webb, D. F., Final Report, 1 March 2010). It included eight modifications for transmittal of the funding to Boston College. Some highlights of this work are summarized below in Section 2. Meetings, publications and presentations fully or partially supported by this grant are listed in Section 3.

2. RESULTS

During the eight years prior to this grant, the P.I. was involved with the STEREO SECCHI consortium as the designated coordinator of space weather modeling for the SECCHI team and as a member of the working group of the HI team. He was and continues to be co-coordinator with Doug Biesecker of NOAA SWPC of the STEREO Space Weather Group, and has developed and maintains a mailing list and a website on STEREO Space Weather at http://secchi.nrl.navy.mil/spwx/. During this entire period through the period of performance of this grant, Webb has participated in most of the SECCHI Consortium and STEREO SWG meetings. He has participated in discussions on halo CMEs and space weather, development of the HI observing program, and coordination of space weather activities between the SECCHI experiments and the other STEREO instruments.

NASA's STEREO mission spacecraft were launched on October 25, 2006 and inserted into heliocentric ~1 AU orbits; the spacecraft drift apart at 22.5° per year. The CME rate was low during the extended solar minimum but has increased during the rise to maximum of cycle 24. The PI has investigated the CME vs. sunspot number (SSN) rates during this period (Figure 1). Cycle 23 lasted ~13 years with an unusually long decline with its minimum in late 2008. With the STEREO data and the automatic catalogs, we now have six independent (white light) CME rates from 2007 to the present. Despite differences in amplitude, the CME rate has continued to track the SSN through its minimum over the last several cycles. The linear relationship between CME rate and SSNs was first shown by Webb and Howard (JGR, 1994) and recently confirmed for Cycle 23 by Robbrecht et al. (JGR, 2009). However, since 2011 the CME rate appears to be diverging from the SSN, possibly related to the weakness of the cycle 23–24 polar fields. The PI is continuing to investigate these differences.

During the period of this grant Webb has been involved in the data analysis for the joint complementary science that is possible with SMEI and STEREO observations since the STEREO launch. During the 8.5 years from the start of routine observations in February 2003 until its decommissioning in September 2011, SMEI observed ~400 ICMEs in the inner heliosphere. Webb has been at the forefront of their analyses (see references). SMEI provides global context observations for the SECCHI HIs as well as a "third eye" view from Earth orbit. This combination of the limited-field HI and all-sky SMEI observations forms a unique data set for viewing dense structures in the inner heliosphere. Many of the papers and presentations listed in Section III involve results that used the HI and SMEI data to help develop a new understanding of the structure of CMEs and how they propagate in the heliosphere (e.g., Johnston et al., 2009; Jackson et al., 2010; Liu et al., 2012; Harrison et al., 2012; Odstrcil et al., 2012; Moestl et al., 2012; Howard et al., 2013; Webb et al., 2014).

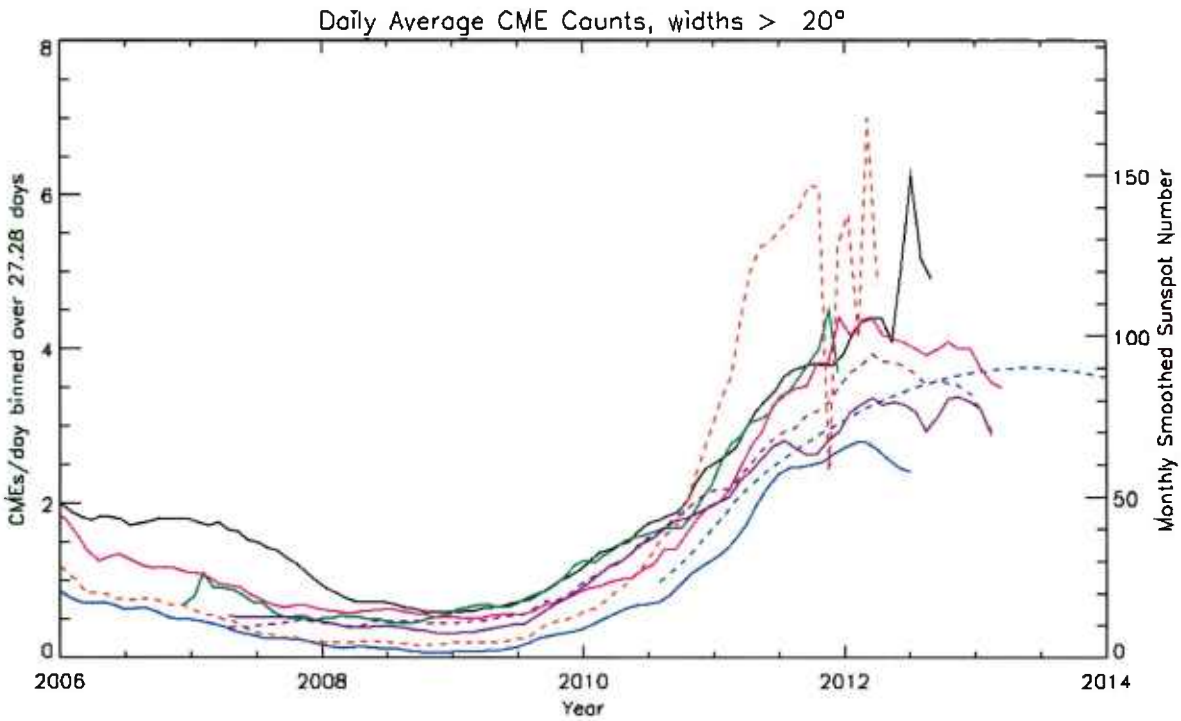

Figure 1. Comparison of CME and SSN rates from 2006 to the present. Manual and automatic CME rates are from the LASCO and STEREO coronagraphs, providing 6 independent measurements of CME rate. Note that the average time of the minimum for both CMEs and SSN was in late 2008. The average CME rate = 0.35/day. The predicted SSN maximum for cycle 24 is ~90 in 2013. The actual SSN is tracking below the predicted curve. From Webb presentation at LWS Workshop, March 2013.

During this period the PI's work involved research and development of techniques for the reduction and analyses of the data returned from the SECCHI instruments to maximize the scientific return of the STEREO mission. This effort was focused on understanding the origins of CMEs, their transport through the solar wind, their in-situ signatures at the STEREO and L1 locations, and their interaction with Earth's environment. Specifically, the P.I.:

- He investigated the solar origins of CMEs and related geoeffective phenomena, using data including halo CMEs, whose source regions can be well observed on the solar disk, observed by LASCO, SECCHI and SMEI, with supporting observations from SOHO EIT, TRACE, Hinode XRT, and ground-based MLSO K-coronameter data (e.g., Webb et al., 2010; 2011). Comparison of the data sets on CMEs was made with observations of filament eruptions, coronal arcades and dimmings and flares and the interplanetary signatures of these disturbances.
- (b) The magnetic topology of CMEs was studied to better understand the magnetic disconnection/flux rope formation process. Webb developed a catalog of SOHO LASCO ray-type structures following CMEs and was involved in several analyses of these data including a comparison with SOHO UVCS observations of current sheets (e.g., Murphy et al., 2011; Ciaravella et al., 2012; Ling et al., 2014).
- (c) He examined the nature of the interplanetary structures related to CMEs with other

unusual interplanetary transient flows such as magnetic clouds, bidirectional particle events, He enhancements, and shocks. These studies utilized intercomparisions among LASCO and SMEI halo CMEs and ACE, Wind and other spacecraft near Earth, and with CMEs launched towards one or both of the STEREO spacecraft that engulf the IMPACT and PLASTIC in-situ experiments (e.g., Liu et al., 2012; Harrison et al., 2012; Odstrcil et al., 2012; Moestl et al., 2012; Howard et al., 2013; Webb et al., 2014);

- (d) He continued the studies with SMEI data to image and track CMEs and determine their characteristics in near-Earth space. As demonstrated, e.g., by Webb et al. (2009; 2012; 2014) and Howard et al., 2013), SMEI results are directly applicable to analyses of the STEREO observations, especially the HI images, for estimating the geometry, density/mass and kinematics of CMEs.

The P.I. contributed to the analyses of the observations from the HI instruments on each spacecraft. He utilized the experience of the SMEI team in analyzing SMEI data to contribute to data analysis of the HI observations, both for HI-only observations and joint observations with the SECCHI EUVI and coronagraph instruments. He contributed to analysis of the data acquired from joint observing programs with these instruments and the other STEREO in-situ experiments, and between the HIs and SMEI and with Hinode and the Solar Dynamics Observatory after its launch in 2010 (see above references).

The P.I. continued his work on coordination and development of space weather-related research and forecasting tools using the STEREO data. He helped develop the near-real time monitoring capabilities of the Beacon mode of the STEREO mission, including helping to coordinate efforts with the NOAA SWPC, the AFRL SWCOE, the Air Force Weather Agency and the Navy for the use of the Beacon and other STEREO data for space weather forecasting purposes for the DoD. He continued to maintain the STEREO Space Weather website and mailing lists, and a catalog of about 20 well-observed Sun-to-STEREO events.

These Sun-to-STEREO events provide important information on the geometry, propagation and internal structure of CMEs. For example, we know that most of these CMEs also had magnetic cloud signatures at 1 AU. These Sun-to-STEREO/L1 data sets were used for forecasting space weather events. During 2010–2011, the STEREO Group members made near-real time event predictions utilizing the Beacon data for three events: 8–12 April 2010 (Davis et al., 2011), the 30 July–4 August 2010 series of multiple events e.g., Harrison et al. (2012), and the 15–18 February 2011 X–class flare–CME (Webb 2013). The Group predictions for these three sets of events were based on several models and techniques. We intercompared the results of the near-real time runs of these techniques to forecast the time of Earth arrival of each CME. Both the time that the prediction was issued and the predicted time of arrival were recorded for each run. Figure 2 is a plot of prediction accuracy vs. the time the prediction was made for the 15 Feb. 2011 event (Webb 2013). Predictions using primarily coronagraph data (LASCO or STEREO CORs) are in blue and those including HI data (SMEI or STEREO HIs) are in red.

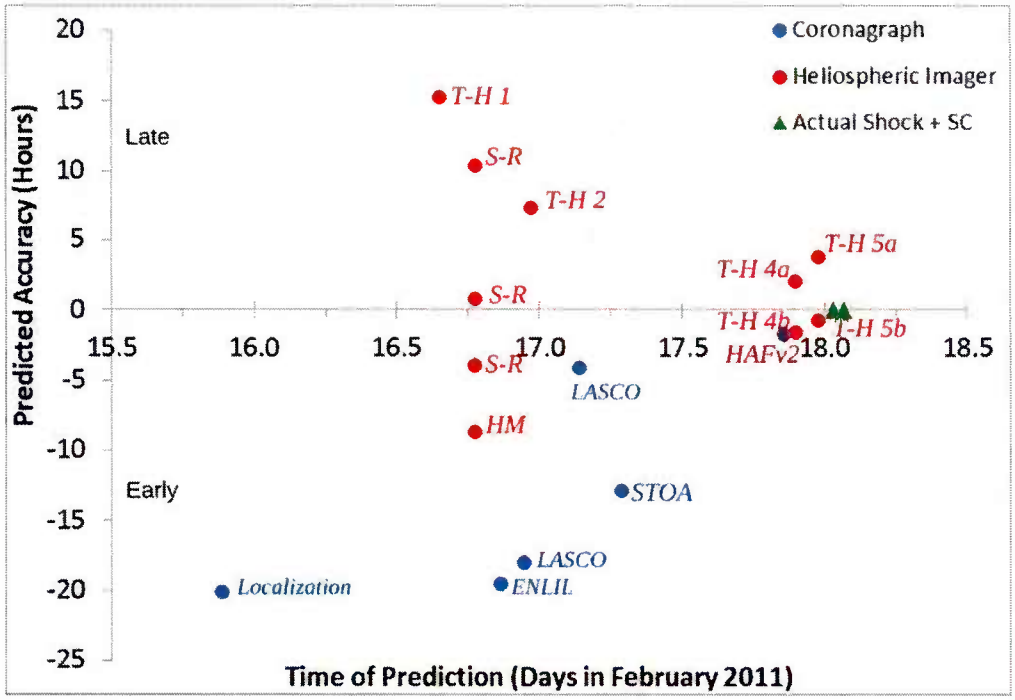

Figure 2. Example of space weather forecasting for the 15 February 2011 halo CME. Plot of prediction accuracy vs the time of prediction for the range of model runs. Prediction accuracy is defined as the [actual arrival time – predicted arrival time] where the actual AT is defined as the shock time at ACE (L1): 18 February, 00:42 UT, the first green triangle on the plot. Model predictions using coronagraph observations are in blue and those using heliospheric imager data are in red. Points lying above the horizontal 0–hour line are positive and therefore "late" and those lying below the line are negative or "early". The best predictions should be near the 0–line and near the left side, i.e, be accurate and have a long lead time. After Webb (2103).

3. MEETINGS, PUBLICATIONS AND PRESENTATIONS

3.1. Meetings

The PI's preparation for and/or participation in the following STEREO Science Working Group, SECCHI Consortium and general scientific meetings was fully or partly funded under this grant:

The PI attended 3 of the last 4 STEREO Science Working Group (SWG) meetings, and reported on the Space Weather Group and on scientific results:

- SWG #20, October 27-29, 2009, Inns and Spas at Mill Falls, Meredith, New Hampshire
- SWG #22: 14 April 2011, by telecon

The PI attended the final SECCHI consortium meeting, and SWG #21, with topics pertinent to space weather or with separate space weather sessions, held 24-26 March 2010 in Dublin, Ireland.

The PI attended these general scientific meetings and presented results pertinent to this grant. The presentations are listed in Section 3.3 below.

- WHI-2 Meeting, 9-13 November 2009, Boulder, CO
- Fall AGU Meeting, 14–18 Dec. 2009, San Francisco
- SORCE Science Meeting, Keystone, CO, 19-21 May 2010
- AGU Meeting of the Americas, Foz do Iguassu, Brazil, 8-12 August 2010
- Fall AGU Meeting, 13–17 Dec. 2010, San Francisco
- LWS-SDO Workshop, The Many Spectra of Solar Activity, Squaw Valley, CA, 1-5 May 2011
- IUGG 2011 General Assembly, Melbourne, Australia, 3-7 July 2011
- Fall AGU Meeting, 5-9 Dec. 2011, San Francisco
- IAU XXVIII General Assembly, 20-31 August 2012, JD03 and SpS10 meetings, Beijing, China
- In-Situ Heliospheric Science Symposium, JHU-APL, 18-20 Sept. 2012
- New England Space Science Consortium meeting, UNH, NH, 24 Oct. 2012
- International Symposium on Solar-Terrestrial Physics, November 6 - 9, 2012 at Indian Institute of Science, Education and Research, Pune, India
- Fall AGU Meeting, 3-7 Dec. 2012, San Francisco
- LWS Solar Dynamics Observatory 2013 Science Workshop, March 3-8, 2013, Hyatt Regency Chesapeake Bay, Cambridge, MD
- SHINE 2013, 24-28 June 2013, Buford, GA

3.2. Publications

Scientific publications resulting from work partially or fully funded by this grant:

Johnston, Janet C., David F. Webb, Donald C. Norquist, and Thomas A. Kuchar, "Imaging Coronal Mass Ejections and Other Heliospheric Phenomena: Six years of Observations and Implications for Future Capabilities", Proc. SPIE, 7438, 74380N, doi:10.1117/12.828664 (2009)

Webb, D.F., D.A. Biesecker, N. Gopalswamy, O.C. St. Cyr, J.M. Davila, B.J. Thompson, K.D.C. Simunac and Janet C. Johnston, "Using STEREO-B as an L5 Space Weather Pathfinder Mission", Space Research Today, 178, 10-16 (2010)

Webb, D.F., S.E. Gibson and B.J. Thompson, "Whole Heliosphere Interval: Overview of JD16", in Highlights of Astronomy, vol. 15, IAU, I.F. Corbett, ed., Cambridge Univ. Press (2010)

Kahler, S.W. and D. F. Webb, "Tracking Nonradial Motions and Azimuthal Expansions of Interplanetary CME with the Solar Mass Ejection Imager", Proc. of Solar Wind 12 Workshop, AIP, 1216, 408–411 (2010)

Jackson, B. V., A. Buffington, P. P. Hick, J. M. Clover, M. M. Bisi, and D. F. Webb, The 26 April 2008 CME: SMEI 3-D reconstruction of an ICME interacting with a co-rotating solar wind density enhancement", Solar Phys., 724, 829-834 (2010)

Gibson, S.E., D. F. Webb and B. J. Thompson, "The Whole Heliosphere Interval in the context of the current solar minimum", ASP Conference Series, Vol.428, p. 223, S.R. Cranmer, J.T. Hoeksema and J.L. Kohl (eds.) (2010)

Davis, C. J., C. A. de Koning, J. A. Davies, D. Biesecker, G. Millward, M. Dryer, C. Deehr, D. F. Webb, K. Schenk, S. Freeland, C. Möstl, C. J. Farrugia, "A comparison of Space Weather analysis techniques used to predict the arrival of the Earth-directed CME and its shockwave launched on 8 April 2010", Space Weather, 9, S01005, doi:10.1029/2010SW000620 (2011)

Webb, D.F., H. Cremades, A. C. Sterling, C. H. Mandrini, S. Dasso, S. E. Gibson, D. A. Haber, R. W. Komm, G. J. D. Petrie, P. S. McIntosh, B. T. Welsch and S. P. Plunkett," The Global Context of Solar Activity During the Whole Heliosphere Interval Campaign", Solar Phys., 274, 57-86, DOI 10.1007/s11207-011-9787-5 (2011)

Gopalswamy, N., J. M. Davila, O. C. St. Cyr, T. Duvall, E. Sittler, R. J. MacDowall, A. Szabo, and M. Collie, J. Johnston, D. F. Webb, E. W. Cliver, S. W. Kahler, F. Auchère, M. Maksimovic, J.-L. Bougeret, B. Heber, S. Vennerstrom, C. de Koning, D. Biesecker, V. Pizzo, R. L. Moore, A. Sterling, A. Vourlidas, R. A. Howard, J. Zhang, B. Vrsnak, P. Rajaguru, "Earth-Affecting Solar Causes Observatory (EASCO): A New View from Sun-Earth L5", Decadal Survey White Paper, Nov. 2010

Vourlidas, A., R. Howard, Y.-K. Ko, D. Biesecker, S. Krucker, M. Thomson, T. Bogdan, C. St Cyr, J. Davila, G. Doschek, N. Gopalswamy, C. Korendyke, M. Laming, P. Liewer, R. Lin, S.

Plunkett, D. Socker, S. Tomczyk, D. Webb, "Mission to the Sun-Earth L5 Lagrangian Point: An Optimal Platform for Heliophysics & Space Weather Research", Decadal Survey White Paper, Nov. 2010

Woods, Thomas N., Rachel Hock, Frank Eparvier, Andrew R. Jones, Phillip C. Chamberlin, James A. Klimchuk, Leonid Didkovsky, Darrell Judge, John Mariska, Harry Warren, Carolus J. Schrijver, David F. Webb, Scott Bailey, and W. Kent Tobiska, New Solar Extreme Ultraviolet Irradiance Observations During Flares, Astrophys. J., 739, 59 (2011).

Thompson, Barbara J., Sarah E. Gibson, Peter C. Schroeder, David F. Webb, Charles N. Arge, Mario M. Bisi, Giuliana de Toma, Barbara A. Emery, Antoinette B. Galvin, Deborah A. Haber, Bernard. V. Jackson, Elizabeth A. Jensen, Robert J. Leamon, Jiuhou Lei, Periasamy K. Manoharan, M. Leila Mays, Patrick S. McIntosh, Gordon J. D. Petrie, Simon P. Plunkett, Liying Qian, Peter Riley, Steven T. Suess, Munetoshi Tokumaru, Brian T. Welsch, Thomas N. Woods, A Snapshot of the Sun Near Solar Minimum: The Whole Heliosphere Interval, WHI SI, Solar Phys., 274, 29-56, DOI 10.1007/s11207-011-9891-6 (2011).

Gibson, S.E., G. de Toma, B. Emery, P. Riley, L. Zhao, Y. Elsworth, R.J. Leamon, J. Lei, S. McIntosh, R.A. Mewaldt, B.J. Thompson, and D. Webb, The Whole Heliosphere Interval in the Context of a Long and Structured Solar Minimum: An Overview from Sun to Earth, WHI SI, Solar Phys., 274, 5-27, DOI 10.1007/s11207-011-9921-4 (2011).

N. A. Murphy, M. P. Miralles, C. L. Pope, J. C. Raymond, K. K. Reeves, D. B. Seaton, and D. F. Webb, "Asymmetric Magnetic Reconnection in Coronal Mass Ejection Current Sheets," in *The Fifth Hinode Science Meeting: Exploring the Active Sun*, ASP Conf. Ser., Vol 456, eds L. Golub, I. De Moortel, and T. Shimizu, pages 199-201 (2012).

Webb, David F. and Timothy A. Howard, Coronal Mass Ejections: Observations, Living Rev. Solar Phys. (http://www.livingreviews.org/lrsp-2012-3), 9, 3 (2012).

Harrison, R.A., J.A. Davies, C. Möstl, Y. Liu, M. Temmer, M.M. Bisi, J.P. Eastwood, C.A. deKoning, N. Nitta, C.J. Farrugia, R.J. Forsyth, B.V. Jackson, E.A. Jensen, E.K.J. Kilpua, D. Odstrcil, T. Rollett, D.F. Webb, "An analysis of the onset and propagation of the multiple coronal mass ejection events of 01 August 2010", Astrophys. J., 750, 45 (2012).

Webb, David F., "CMEs and Their Heliospheric Aspects", in IAU Commission 49 report, Trans IAU, vol. XXVIIIA, Reports on Astronomy 2009-2012, I. Corbett, ed., CUP (2012).

Liu, Ying, Janet G. Luhmann, Christian Moestl, Juan Martinez Oliveros, Stuart Bale, Robert P. Lin, Richard A. Harrison, Manuela Temmer, David F. Webb, and Dusan Odstrcil, Interactions between Coronal Mass Ejections Viewed in Coordinated Imaging and In Situ Observations, Astrophys. J.Lett., 746, L15 (2012).

Ciaravella, A., D.F. Webb, S. Giordano and J.C. Raymond, Bright Ray-like Features in the Aftermath of CMEs: White Light vs UV Spectra, Astrophys. J., 766, 65 (2012).

Webb, D.F., C. Möstl, B.V. Jackson, M.M. Bisi, T.A. Howard, T. Mulligan, E.A. Jensen, L. K. Jian, J.A. Davies, C.A. de Koning, Y. Liu, M. Temmer, J.M. Clover, C.J. Farrugia, R.A. Harrison, N. Nitta, D. Odstrcil, S.J. Tappin, and H.-S. Yu, Heliospheric Imaging of 3-D Density Structures During the Multiple Coronal Mass Ejections of Late July to Early August 2010, Solar Phys, TI: Observations & Modeling of the Heliosphere, 285, 317-348 (2012).

M¨ostl, C., C. J. Farrugia, E. K. J. Kilpua, L. K. Jian, Y. Liu, J. P. Eastwood, R. A. Harrison, D. F. Webb, M. Temmer, D. Odstrcil, J. A. Davies, T. Rollett, J. G. Luhmann, N. Nitta, T. Mulligan, E. A. Jensen, R. Forsyth, B. Lavraud, C. A. de Koning, A. M. Veronig, A. B. Galvin, T. L. Zhang, and B. J. Anderson, Multi-Point Shock and Flux Rope Analysis of Multiple Interplanetary Coronal Mass Ejections Around 2010 August 1 in the Inner Heliosphere, Astrophys. J., 758, 10 (2012).

Odstrcil, D., H. Xie, C. A. de Koning, A. P. Rouillard, C. Möstl, M. Temmer, L. K. Jian, M. Dryer, J. A. Davies, C. J. Davis, R. A. Harrison, D. F. Webb, C. N. Arge, T.-L. Zhang, Numerical heliospheric simulation as an assisting tool for interpretation of the "first STEREO multi-event", four coronal mass ejections (CMEs) of 2010-08-01, J. Geophys. Res., , in review (2012).

Howard, T.A., M. M. Bisi, A. Buffington, J. M. Clover, M. P. Cooke, C. J. Eyles, P. P. Hick, P. E. Holladay, B. V. Jackson, J. C. Johnston, S. W. Kahler, T. A. Kuchar, D. R. Mizuno, A. J. Penny, S. D. Price, R. R. Radick, G. M. Simnett, S. J. Tappin, N. R. Waltham and D. F. Webb, The Solar Mass Ejection Imager and Its Heliospheric Imaging Legacy, Space Sci. Rev., 180, 1-38, 201310.1007/s11214-013-9992-7 (2013)

Webb, David F., Coronal Mass Ejections and Space Weather, in ASI Conference Series of the Bulletin of the Astronomical Society of India, Eds: P B Rao, N Gopalswamy, S S Hasan, P Subramanian, Vol. xx, in press (2013).

Ling, A.G., D. F. Webb, J. Burkepile and E. W. Cliver, Development of a Current Sheet in the Wake of a Fast CME, *Astrophys. J.,* in press (2013).

Webb, David F., Coronal Mass Ejections and Space Weather, in ASI Conference Series of the Bulletin of the Astronomical Society of India, Eds: P B Rao, N Gopalswamy, S S Hasan, P Subramanian, Vol. xx, in press (2013).

Webb, D.F., M.M. Bisi, C.A. de Koning, C.J. Farrugia, B.V. Jackson, L. K. Jian, N. Lugaz, K. Marubashi, C. Möstl, E.P. Romashets, B.E. Wood and H-S Yu, The Launch and Heliospheric Propagation of a CME in January 2010 from the Sun to STEREO-B, submitted, 2014.

3.3. Presentations

Presentations at scientific meetings resulting from work partially or fully funded by this grant:

Webb, D F; A. B. Galvin; N. Gopalswamy; T. A. Howard; A. A. Reinard; B. Jackson; C. Davis,

"The 26 April 2008 CME; a Case Study Tracking a CME into the Heliosphere", EOS Trans. AGU, Fall Meeting Suppl., Abstract SH41A-1640, p. 319, 14–18 Dec. 2009.

D.F. Webb, N. Nitta, G.D.R. Attrill, K. Marubashi, T.A. Howard, S.J. Tappin and B.V. Jackson, "CME Observations Involving a Coronal Wave and Magnetic Cloud", STEREO SECCHI Workshop, Dublin, Ire., 22-23 March 2010.

David Webb and Sarah Gibson, "Comparison of Solar Wind and CME Data: Current and Previous Solar Minima", SORCE Science Meeting, Keystone, CO, 19-21 May 2010.

Webb, David F., "The Global Context of Solar Activity During the Whole Heliosphere Interval Campaign", Bull. AAS, 42(3), p. 883, 2010.

Webb, David F., "Comparison of Solar Wind and Transient Data During the Last Two Solar Minima", The Meeting of the Americas, Foz do Iguassu, Brazil, Abstract SH14A-03, p. 11, 8-12 August 2010.

Janet. C. Johnston, Thomas. A. Kuchar and David. F. Webb, "Forecasting Geomagnetic Storms: Tracking Hazardous Solar Ejecta with the Next Generation Heliospheric Imaging System", SEASONS meeting, JHU/APL, 2-5 Nov. 2010.

D F Webb, E W Cliver, N V Nitta, G D Attrill, K Marubashi, T A Howard, J Tappin, B V Jackson, SH41A-1778 POSTER: End-to-End Observations and Modeling of the 17-21 January 2010 CME/ICME, p. 377, AGU Fall Meeting Program, 13-17 August 2010.

J C Johnston, T A Kuchar, D F Webb, SH54D-01: The Role of Short-Term Precursors in a Hybrid CME Forecast, p. 557, AGU Fall Meeting Program, 13-17 August 2010.

D F Webb, J C Johnston, T A Kuchar, J Tappin, T A Howard, SH54D-05: Forecasting Earth Arrivals of CMEs with Heliospheric Imagers (Invited), p. 557, AGU Fall Meeting Program, 13-17 August 2010.

D. F. Webb, M. M. Bisi, C. A. de Koning, R. A. Harrison, T. A. Howard, B. V. Jackson, J. C. Johnston, E. Kilpua, T. Kuchar, C. Moestl, J. Tappin, Studying the Characteristics of CMEs Using Combined Imaging and In-situ Data from STEREO, SOHO and other L1 spacecraft, SMEI and SDO, LWS-SDO Workshop, The Many Spectra of Solar Activity, Squaw Valley, CA, 1-5 May 2011, Abstract Book, poster no. 4, p. 45.

D. F. Webb, M. M. Bisi, C. A. de Koning, R. A. Harrison, T. A. Howard, B. V. Jackson, J. C. Johnston, E. Kilpua, T. Kuchar, C. Moestl, J. Tappin, Studying the Characteristics of CMEs Using Combined Imaging and In-situ Data from STEREO, SOHO and other L1 spacecraft, SMEI and SDO, IUGG 2011 General Assembly, Melbourne, Australia, Program Book, A101S6, p. 144, 3 July 2011.

Timothy A Howard and David F Webb, Utilizing Heliospheric Imagers to Improve Space Weather Forecasting, , IUGG 2011 General Assembly, Melbourne, Australia, Program Book,

A121S5, p. 202, 6 July 2011.

David F. Webb, 2011, SH22A-01: "Space Weather from STEREO and Near-Real Time Forecasts of CMEs" (Invited), AGU Fall Meeting Program, 5-9 Dec. 2011.

David F. Webb; Bernard V. Jackson; Mario M. Bisi; Timothy A. Howard, SH31C-2024: "Using Global Heliospheric Reconstructions to Separate Multiple CME and CIR Flows", AGU Fall Meeting Program, 5-9 Dec. 2011.

Bernard V. Jackson; John M. Clover; Andrew Buffington; P. P. Hick; Mario M. Bisi; Katsuhide Marubashi; David F. Webb, SH21A-1909: "Imaging Coronal Mass Ejections and Large-Scale Solar Wind Structure Using Thomson-Scattering Measurements from SMEI", AGU Fall Meeting Program, 5-9 Dec. 2011.

Webb, David, Solar Cycle Variation of Coronal Mass Ejections, , in IAU XXVIII General Assembly, 20-31 August 2012, Programme Book, JD03, 3-D Views of the Cycling Sun in Stellar Context,, p. 96.

Webb, D.F., T.A. Howard, C.E. DeForest and D.J. McComas, CMEs and the Buildup of Magnetic Flux in the heliosphere, in IAU XXVIII General Assembly, 20-31 August 2012, Programme Book, SpS10, Dynamics of Star-Planet Relations, p. 37.

David Webb: Solar cycle variations of CMEs. Presented in Session A of the In-Situ Heliospheric Science Symposium, JHU-APL, 18-20 Sept. 2012.

David Webb, New SECCHI Processing for Heliospheric Transients. Presented in Session D of the In-Situ Heliospheric Science Symposium, JHU-APL, 18-20 Sept. 2012.

David Webb, New SECCHI Processing Pipeline for CMEs. Presented at NSSEC meeting, UNH, 24 Oct. 2012.

David F. Webb, Coronal Mass Ejections and Space Weather. Invited presentation at the International Symposium on Solar-Terrestrial Physics, held November 6 - 9, 2012 at the Indian Institute of Science, Education and Research, Pune, India.

D. Webb and S. Gibson, Solar Cycles 23 and 24: Effects in the Heliosphere. SH12A-06; (Invited), AGU Fall Meeting Program, 3-7 Dec. 2012.

David Webb, Solar Cycle Variation of Coronal Mass Ejections, oral presentation at the LWS Solar Dynamics Observatory 2013 Science Workshop, March 3-8, 2013 at the Hyatt Regency Chesapeake Bay, Cambridge, MD.

3.3. Presentations

Presentations at scientific meetings resulting from work partially or fully funded by this grant.

Morrill, J.S. et al. in "The Impact of Geometry on CME Observations Made by SECCHI", Eos Trans. AGU, 88(23), Jt. Assembly Suppl., Abstract SH.41A-11, 2007

Webb, D.F. et al., "First Combined Observations of CMEs by the LASCO Coronagraphs, SMEI and the STEREO SECCHI Heliospherical Imagers", BAAS, 39, no. 1, Abstract 119.06, p. 244, 2007.

Webb, D.F. et al., "CME Propagation in the Inner Heliosphere Using SMEI and STEREO SECCHI HI Data", presented at SHINE 2007 Workshop, 30 July – 3 Aug. 2007, Whistler, Canada

Webb, D.F. et al., "Study of CME Propagation in the Inner Heliosphere", contributed talk presented at Living With a Star science meeting, 10-13 Sept. 2007, Boulder, CO. Abstract booklet, p. 23, 2007.

Webb, D.F. et al., "Study of CME Propagation in the Inner Heliosphere", contributed talk presented at Intl. CAWSES Symposium, 23-27 Oct. 2007, Kyoto. Program booklet, p. 19, 2007.

Webb, D.F. et al., "Study of CME Propagation in the Inner Heliosphere", talk presented at the STEREO SWG #17, 13-14 Nov. 2007, Caltech, Pasadena, CA, 2007.

Howard, T.A., D.F. Webb and J.C. Johnston, "ICME Evolution Characteristics in the Inner Heliosphere Observed Using SMEI and STEREO/SECCHI/HI Data", *EOS Trans. AGU*, 88(52), Fall Meet. Suppl., Abstract SH32A-0789, 2007.

Webb, David, "The Importance of Coronal Mass Ejections to Heliophysics", INVITED talk presented at the Latin American IHY School, 14 Feb. 2008, San Paulo, Brazil, Program & Abstract Book, p. 7, 2008.

Webb, D.F., T. A. Howard, and J. S. Morrill, "Study of the Propagation of CMEs in the Inner Heliosphere Using SMEI and SECCHI-HI Data", talk presented at the SECCHI workshop, 24 April 2008, Meudon, FR, 2008.

Webb, D.F., T. A. Howard, G. Fry and D. Odstricil, "Study of the Propagation of CMEs in the Inner Heliosphere Using SMEI and STEREO-SECCHI-HI Data", talk presented at the Spring AGU/SPD meeting, 27-20 May 2008, Ft. Lauderdale, FL, 2008.

Jackson, B V, M.M. Bisi, P.Paul Hick, A. Buffington, J.M. Clover, and D.F. Webb, "SMEI Observations of the Heliosphere During WHI", poster presented at the Spring AGU/SPD meeting, 27-20 May 2008, Ft. Lauderdale, FL, 2008.

Webb, D., "Observations of CME/ICME Events Using Data from Hinode, LASCO, SMEI and STEREO", INVITED talk presented at the COSPAR meeting, 13 July 2008, Montreal, CAN, 2008.

Webb, D., "Observational Evidence of Current Sheets Trailing Coronal Mass Ejections", INVITED talk presented at the COSPAR meeting, 13 July 2008, Montreal, CAN, 2008.

Reeves, K.K. et al. , "Observations and analysis of the April 9, 2008 CME using STEREO, Hinode TRACE and SoHO data", *EOS Trans. AGU*, 29 Dec. 2008, Fall Meeting Suppl., Abstract SH12A-04, 2008.

Thompson, B, S. et al., "The Whole Heliosphere Interval: Campaign Summaries and Early Results", *EOS Trans. AGU*, 29 Dec. 2008, Fall Meeting Suppl., Abstract SH21C-01, 2008.

Webb, D F, J C Johnston, C D Fry, T A Kuchar, "Using Heliospheric Imaging for Storm Forecasting: SMEI CME Observations as a Tool for Operational Forecasting at AFWA", *EOS Trans. AGU*, 29 Dec. 2008, Fall Meeting Suppl., Abstract SA-41B-02, 2008.

Johnston, J.C., K S Balasubramaniam, C D Fry, T A Kuchar, D F Webb. "Forecasting Frontiers Part I: Solar Drivers of Space Weather Observations", *EOS Trans. AGU*, 29 Dcc. 2008, Fall Meeting Suppl., Abstract SA-51A-1532, 2008.

Webb, D.F., "Space Weather with STEREO: Sun to STEREO (Earth) Connection Events", INVITED talk at STEREO PLASTIC Team Meeting, Concord, NH, 8 April 2009.

Webb, D.F., D. Biesecker, T.A.Howard, J.G. Luhmann, Y. Li, A.B. Galvin, R.A. Howard and B.V. Jackson, "CMEs in the Heliosphere Observed with Combined Imaging and In-situ Data from LASCO, STEREO and SMEI", STEREO-3/SOHO-22 Workshop, Bournemouth, UK, 27 Apr – 1 May 2009, Abstract Book, p. 90, 2009.

Webb, D.F., D. Biesecker, N. Gopalswamy, O.C. St. Cyr, J.M. Davila and K. Simunac, "Using STEREO-B as an L5 Space Weather Pathfinder Mission", STEREO-3/SOHO-22 Workshop, Bournemouth, UK, 27 Apr – 1 May 2009, Abstract Book, p. 199, 2009.

Webb, D.F., D. Biesecker, T.A.Howard, J.G. Luhmann, Y. Li, A.B. Galvin, R.A. Howard and B.V. Jackson , "CMEs in the Heliosphere Observed with Combined Imaging and In-situ Data from LASCO, STEREO and SMEI", Bull. AAS, 41(2), p. 855, 2009.

Kahler S. and D. Webb, "Tracking Nonradial Motions and Azimuthal Expansions of Interplanetary CMEs With the Solar Mass Ejection Imager", Solar Wind 12 Book of Abstracts, p. 126, St Malo, France, 21-26 June 2009.

Webb, D. F., A. Galvin, N. Gopalswamy, D. Haber, P. McIntosh, B. V. Jackson, M. M. Bisi, S. P. Plunkett, "Tracking CMEs from the Sun into the Heliosphere During the WHI Period", IAU 27th GA Book of Abstracts, JD16, p. 383, Rio de Janeiro, BR, 3-14 Aug. 2009.

Jackson, B.V., M. M. Bisi, P. P. Hick, A. Buffington, J. M. Clover, D. F. Webb, M. Tokumaru, "SMEI Remote Sensing and the 3D Reconstruction of Corotating Heliospheric Structures During WHI", IAU 27th GA Book of Abstracts, JD16, p. 384, Rio de Janeiro, BR, 3-14 Aug. 2009.

Webb, D.F., A. Galvin, N. Gopalswamy, D. Haber, P. McIntosh, B. V. Jackson, M.M. Bisi and S. P. Plunkett, "Tracking CMEs from the Sun into the Heliosphere During the WHI Period", SOHO 23 Program booklet, p. 119, Northeast Harbor, ME, 21-25 September 2009.

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M. and D.F. Webb, "SMEI and IPS remote sensing and 3D reconstruction of corotating heliospheric structures during solar minimum", SOHO 23 Program booklet, p. 112, Northeast Harbor, ME, 21-25 September 2009.

Webb, D F; A. B. Galvin; N. Gopalswamy; T. A. Howard; A. A. Reinard; B. Jackson; C. Davis, "The 26 April 2008 CME; a Case Study Tracking a CME into the Heliosphere", EOS Trans. AGU, Fall Meeting Suppl., Abstract SH41A-1640, p. 319, 14–18 Dec. 2009.